(54) Title: METHOD TO DETERMINE THE QUALITY OF EYE-OPTICS
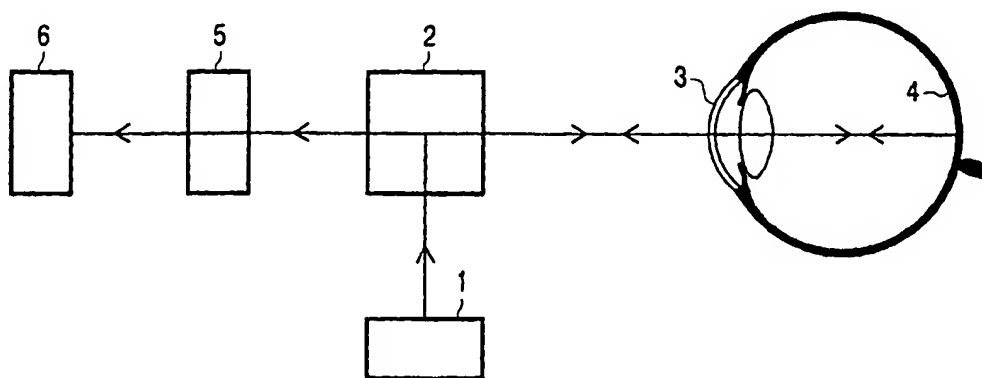
(57) Abstract: The invention relates to a method to determine the quality of eye optics, wherein a light signal is passed into an eye,
producing a spot image on the retina of the eye, that the spot image on the retina produces a secondary light signal that is measured
outside the eye, and that from characteristics of the secondary light signal a measure is derived indicating the quality of the eye optics.
An objective refractometer is utilized, and the signals coming from the refractometer are processed into a single parameter, which
is a measure of the quality of the eye optics.

WO 02/19901 A1

Method to determine the quality of eye-optics

     The invention relates to a method to determine
the quality of eye-optics, wherein a light signal is
passed into an eye, producing a spot image on the retina
of the eye, that the spot image on the retina produces a
5 secondary light signal that is measured outside the eye,
and that from characteristics of the secondary light
signal a gauge is derived indicating the quality of the
eye optics.

     The American patent specification US-A-4,560,259
10 discloses a method directed at determining correction
parameters for the eye that relate to global refractive
aberrations.

     Generally speaking, the following observations
may be made with respect to the process of visual
15 perception in humans.

     The human visual system can be divided into a
number of elements that culminate in a conscious
perception of these surroundings. Light coming from the
surroundings enters the eye via the cornea, pupil and eye
20 lens. Refraction of the light at the cornea and eye lens
produces a projection of the surroundings on the retina.
The retina comprises photoreceptors that convert the light
from said image into electrical signals. These are
transported by the eye nerve to the brain where further
25 processing results in conscious perception. Vision is
determined, among other things, by the quality of the
image that is formed on the retina. Ideally, a point-like
light source produces a point-like light spot on the
retina. Due to various causes, the light spot on the
30 retina will in reality be somewhat spread out. A generally
known reason for this is the global (spherical and
cylindrical) refractive faults that may be corrected by
means of, for example, spectacles or contact lenses. In
addition to the global refractive errors there are other

2

causes determining the quality of the retinal image. These
include local refractive errors, diffusion of light and
diffraction. These imperfections of the eye optics are
corrected less easily. In the case of greatly increased
5   diffusion of light in the eye lens the usual correction
consists of replacing the natural lens with an artificial
lens.

Such a method is known, for example from the
American patent specification US-A-4,560,259. Said known
10   method is directed at determining certain correction
parameters for the eye.

When using objective methods to determine global
refractive errors of the eye, the so-called objective
refractor is applied. With such an objective refractor a
15   light source is projected via a beam splitter onto the
retina of an eye to be examined. A portion of the light
falling on the retina is reflected and leaves the eye
again via the pupil. Via the previously mentioned beam
splitter and focusing optics this light is conducted to a
20   detector, while analysis of the detector signal provides
information about the global refractive errors of the eye.

The image-forming quality of the eye optics
affects both the retinal image (ingoing direction) and the
image formed by the light reflected by the retina (return
25   direction) outside the eye.

According to the invention, this known objective
refractor is utilized such that one single parameter can
be obtained forming a measure of the quality of an image
on the retina, thus including the non-global refractive
30   errors. This parameter is a gauge for the question to
which extent the patient's vision is determined by the
optical characteristics of the examined eye. In this way
it is possible to assess whether it is desirable to
perform surgery, for example to perform surgery on a
35   cataract.

In a following aspect of the method according to
the invention, the same is characterized in that the
refractometer is a knife-edge meter, which is provided

with a light source and preferably a double knife-edge
that forms a slit, and that a series of measurements are
carried out with the same, wherein the position of the
focal point of the light source and slit are varied from
5   in front of the retina to behind the retina of the
examined eye, that for each focal point position a spot
image distribution on the retina is determined wherein a
difference signal in light intensity between an upper
plane portion and a lower plane portion is determined, and
10   that this focus-dependent difference signal is processed
into a single number forming a measure of the quality of
the eye optics, preferably by doing a curve fitting in
order to determine the parameters in the difference signal
function

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$$f(s) = A \bullet \frac{\arctan\left(\frac{s-s_0}{W}\right)}{1+\frac{(s-s_0)^2}{W}} \, ,$$

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wherein the parameters A, s, s_0 and W

have the following meaning:

A = amplitude of the difference signal function

s = the spherical refraction

25   s_0 = the optimal spherical refraction

W = a breadth parameter;

and that the amplitude parameter A is used as measure of
the quality of the eye optics.

Another aspect of the method according to the
30   invention is characterized in that the refractometer is a
wave front sensor, wherein a light source projects a light
spot onto the retina, and in that the secondary light
signal coming from this light spot is measured by means of
a lens grid of the wave front sensor, the pattern of
35   secondary light spots that is measured by the lens grid
being determined and recorded, in that the position of the

measured secondary light spots is compared with a
previously determined position of such light spots in the
absence of optical aberrations in the eye, and in that the
difference signals measured are processed into a single
5   number that is a measure of the quality of the eye optics.
     It is advantageous for a two-dimensional Fourier
transformation to be carried out on the signals coming
from the wave front sensor, and for a null harmonic and
first harmonics to be determined from the Fourier-
10   transformed, the first harmonics subsequently being
normalized to the null harmonic in order to provide a
(dimension-less) number that forms a measure of the
quality of the eye optics.
     The invention will now be elucidated with
15   reference to the drawings, in which:
          - Figure 1 schematically shows the general
construction and working of an objective refractometer;
          - Figure 2 shows the general principle of the
knife-edge test with which the method according to the
20   invention can be applied in a first embodiment;
          - Figure 3, shows another application of the
knife-edge test according to Figure 2;
          - Figure 4 shows the results of a curve fitting
according to a first embodiment of the method according to
25   the invention;
          - Figure 5, schematically shows the principle of
an objective refractometer used in a second embodiment of
the method according to the invention; and
          - Figure 6, shows some measuring results from the
30   second embodiment of the method according to the invention
obtained from a healthy eye and a cataract eye,
respectively.
     The general construction of an objective
refractor is shown in Figure 1. A light source 1 is
35   projected via a beam splitter 2 onto the retina 4 of the
eye 3 to be examined. A portion of the light falling onto
the retina is reflected and leaves the eye via the eye's
pupil. Via a beam splitter 2 and focusing optics 5 this

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light will reach a detector 6. Analysis of the detector
signal provides information on the global refractive
errors of the eye. The image-forming quality of the eye
optics influences both the retinal image (ingoing
5   direction) and the image formed outside the eye (return
direction). This allows the light exiting the eye to be
used for obtaining information about the optical quality.
       The analysis of the quality of the eye optics is
closely related to the choice of particular refraction
10 measurement details. The parameter for describing the
quality of the eye optics will be outlined in more detail
on the basis of two methods of objective refraction
measurement, with reference to the Figures 2, 3 and 4 and
the Figures 5 and 6, respectively.
15   To objectively determine the refraction of an eye
the so-called knife-edge test may be applied. This is
known from the American patent specification US-A-
4,560,259. The principle of the knife-edge test is
depicted in Figure 2.
20   A point-like light source 1 illuminates an
optical system, in this case consisting of one single lens
2. Positioned behind this lens is a knife-edge 3 that is
movable along the optical axis. Behind the focal plane a
screen 4 is positioned. This screen is illuminated by the
25 light beams not blocked by the knife. Depending on the
position of the knife on the optical axis, either the top
or the bottom half of the screen will be illuminated. If
the knife-edge is in the focal plane the screen will be
illuminated evenly.
30   . When applied to the eye, the reflection of light
from the retina is used. This provides an optical system
as schematically illustrated in Figure 3. The light source
may, for example, be a linear one and there may be a
double knife-edge so that a slit is formed. Both the slit
35 and the source are imaged in the eye. Both images can be
moved (simultaneously) with the aid of the projection
optics in the refractor. Just as with the system shown in
Figure 2, the light will be distributed in a specific

manner, this time in the pupillary plane of the eye. In
the application as refractor, an even distribution of
light is sought by means of adjusting the projection
optics. In that case the images of slit and source are at
5   the height of the retina. The projection optics now show
the optimal refraction.

    In addition to the optimal refraction according
to the invention, it is with the aid of said optics also
possible to determine a parameter for describing the
10 quality of the eye optics. If the image of source and slit
are deliberately projected in front of (or behind) the
retina there will be an uneven distribution of light in
the pupillary plane. The abruptness of the transition
between the light and the dark part of the pupil is
15 determined, among other things, by the quality of the eye
optics. Poor eye optics produce a more even distribution
of light in the pupillary plane than good optics. A
detector measures the proportions of light in the top and
bottom half of the pupillary plane. To determine the
20 quality of the eye optics, the detector signals are
analyzed as function of the position of the image of
source and slit.

    A possible manner of analyzing involves making a
scan covering an area of (spherical) refractive errors in
25 a range from -4 to +4 dioptres in 60 steps. The difference
between detector signals from the top and the bottom pupil
half are normalized to the sum of said detector signals.
This signal is henceforth called $f(s)$. With the aid of
data fitting the measurements are reduced to a number of
30 parameters:

$$f(s) = A \bullet \frac{\arctan\left(\frac{s-s_0}{W}\right)}{1+\frac{(s-s_0)^2}{W}} \, ,$$

wherein s is the spherical refraction, s_0 is the optimal spherical refraction, A is the amplitude parameter and W is a breadth parameter.

An example of a scan is shown in Figure 4. This
5   figure shows two scans: One relates to the vertical
distribution of light in the pupil and one to the
horizontal direction. Optimal refraction occurs at the
point where $f(s)$ has a zero-axis crossing: the luminous
intensity is then the same in both pupil halves. The
10 example shown is of an eye with both spherical and
cylindrical aberrations. Due to the cylindrical
aberrations, the horizontal and the vertical scan have
different optimal refractions. The amplitude parameter A,
determined by this method as proposed by the invention, is
15 a measure of the quality of the eye optics. Variations
regarding illumination (slit-shaped or otherwise), and
reproduction (knife forms and detector layout) and
regarding the analysis of the signals obtained
(distribution of the light in the pupil) may be chosen in
20 various ways, all falling within the scope of the
invention.

Figure 5 shows the principle of an automatic
refractor based on the principle of the Shack-Hartmann
wave front sensor. The light source projects a light spot
25 onto the retina. A portion of the light will be reflected
and will move as a spherical wave front in the direction
of the pupil. The refractive properties of the eye lens
and the cornea transform the wave front into a planar
wave, at least in the ideal case. In a real eye there are
30 deviations from a planar wave. The wave front sensor
comprises a grid consisting of miniature lenses positioned
in the pupillary plane. Behind each lens there is a
projection of the light spot on the retina. In the case of
the ideal planar wave this image will be located centrally
35 behind each lens. This produces a regular pattern of light
spots in the focal plane of the lens grid. This pattern is
recorded by an image sensor. Deviations from the ideal
planar wave will henceforth be indicated by $W(x,y)$, the

8

wave front as function of the position x,y in the
pupillary plane. This wave front entails a displacement of
the light spots. This displacement may be recorded as
follows:

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$$\Delta x = f \; \frac{\partial W(x,y)}{\partial x} \; , \quad \Delta y = f \; \frac{\partial W(x,y)}{\partial y} \; ,$$

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f being the distance between lens grid and image sensor,
and Δx, Δy the displacement of the light spots. By
measuring the position of the light spots on the image

15   sensor it is possible to reconstruct the wave front $W(x,y)$.
This wave front contains the information of the local
refractive properties of the eye in the pupillary plane.
    The global spherical and cylindrical refraction leads
to a scaling of the spot pattern. In the case of spherical

20   aberrations this scaling is the same in all directions; in
the case of cylindrical aberrations the scaling along the
axis of the cylindrical aberration will differ from that
perpendicularly thereto. In order to measure the global
refraction it is not necessary to completely reconstruct

25   the wave front. A very efficient manner to determine the
refraction is by means of the two-dimensional Fourier
transformed of the spot pattern. The spot pattern may be
described as: $p(i,k)$, the number of elements both in the i
and the k direction being N. The Fourier transformed of

30   this signal is:

$$P(m,n) = \frac{1}{N} \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} p(i,k) e^{-2j\pi (m\frac{i}{N} + \frac{k}{N})}$$

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    The mean distance of the spot pattern is obtained by
the position of the first harmonics of the Fourier
transformed. Because the wave front sensor measures the

local refraction at a large number of spots on the
pupillary plane, it is possible to select the area in the
pupil over which the global refraction is measured. This
provides a more accurate refraction, especially for eyes
5   that have a naturally large pupillary diameter. It is,
after all, the rim of the pupil where the spherical
aberration manifests itself. At the same time, however, the
light from the rim of the pupil is detected less
efficiently by the photoreceptors in the eye; this is the
10 so-called Stiles-Crawford effect. By normalizing the spot
pattern $p(i,k)$ it is possible to correct for this effect.

     The refraction is not the only information to be
derived from the Fourier transformed. Higher order-
refractive errors, the so-called aberrations, provide a
15 less regular spot pattern. The regularity of the spot
pattern is provided by the intensity of the first harmonic.
By, in accordance with the invention normalizing the
intensity of the first harmonic to the mean intensity (the
null harmonic), a dimensionless number is obtained that
20 represents a measure of the regularity of the spot pattern,
and thus for the optical quality of the eye.

     Figure 6, shows an example of recordings by the wave
front sensor of a healthy eye and of a cataract eye. The
Fourier Parameter (FP) is mentioned both for the central 4
25 mm of the pupillary diameter and for the entire pupil (9
mm).

     · Scattering of the light results in a blurred spot
pattern. This manifests itself in enlarged light spots with
a lower maximum intensity. Because the adjacent light spots
30 run into each other, the minimum intensity between light
spots denotes a measure of the scattering of light in the
eye optics. Normalizing this minimum intensity to the
maximum intensity provides a dimension-less number that is
a measure of the quality of the eye optics, irrespective of
35 the amount of light reflected by the retina.

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CLAIMS

1. A method to determine the quality of eye-optics, wherein a light signal is passed into an eye, producing a spot image on the retina of the eye, that the spot image on the retina produces a secondary light signal that is
5 measured outside the eye, and that from characteristics of the secondary light signal a measure is derived indicating the quality of the eye optics, characterized in that an objective refractometer is utilized, and that the signals coming from the refractometer are processed into a single
10 parameter, which is a measure of the quality of the eye optics.

2. A method according to claim 1, characterized in that the refractometer is a knife-edge meter, which is provided with a light source and preferably a double
15 knife-edge that forms a slit, and that a series of measurements are carried out with the same, wherein the position of the focal point of the light source and slit are varied from in front of the retina to behind the retina of the examined eye, that for each focal point
20 position a spot image distribution on the retina is determined wherein a difference signal in light intensity between an upper plane portion and a lower plane portion is determined, and that this focus-dependent difference signal is processed into a single number forming a measure
25 of the quality of the eye optics.

3. A method according to claim 2, characterized in that a curve fitting is done on the difference signal in order to determine the parameters in the difference signal function

30

$$f(s) = A \cdot \frac{\arctan \left(\frac{s-s_0}{W} \right)}{1 + \frac{(s-s_0)^2}{W}} ,$$

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wherein the parameters A, s, s_0 and W

have the following meaning:

> A = amplitude of the difference signal function
>
> s = the spherical refraction
>
> s_0 = the optimal spherical refraction
>
> W = a breadth parameter;

and that the amplitude parameter A is used as measure of the quality of the eye optics.

4. A method according to claim 1, **characterized in** that the refractometer is a wave front sensor, wherein a light source projects a light spot onto the retina, and in that the secondary light signal coming from this light spot is measured by means of a lens grid of the wave front sensor, the pattern of secondary light spots that is measured by the lens grid being determined and recorded, in that the position of the measured secondary light spots is compared with a previously determined position of such light spots in the absence of optical aberrations in the eye, and in that the difference signals measured are processed into a single number that is a measure of the quality of the eye optics.

5. A method according to claim 4, **characterized in** that a two-dimensional Fourier transformation is carried out on the signals coming from the wave front sensor, and in that a null harmonic and first harmonics are determined from the Fourier-transformed, the first harmonics subsequently being normalized to the null harmonic in order to provide a (dimension-less) number that is a measure of the quality of the eye optics.
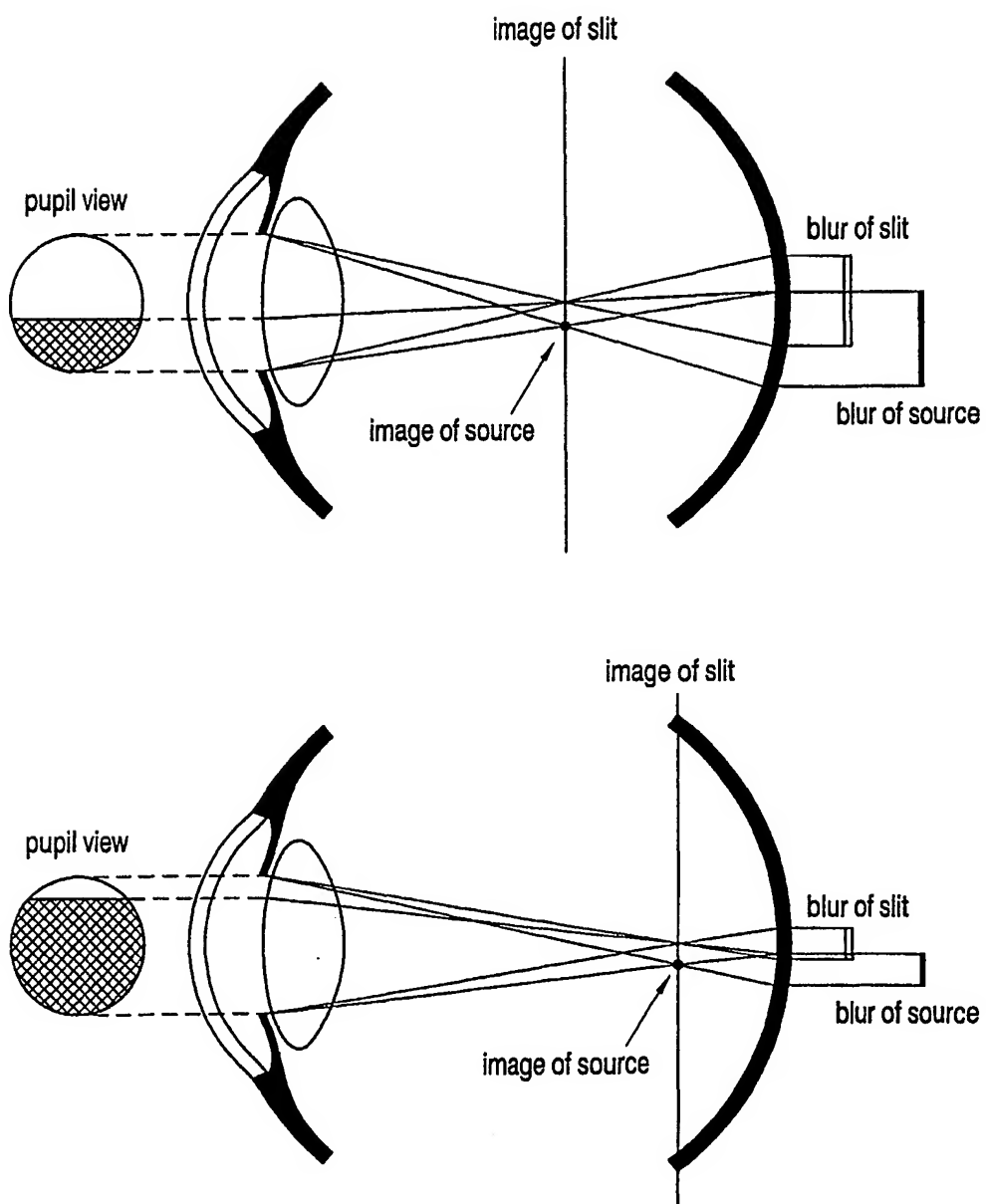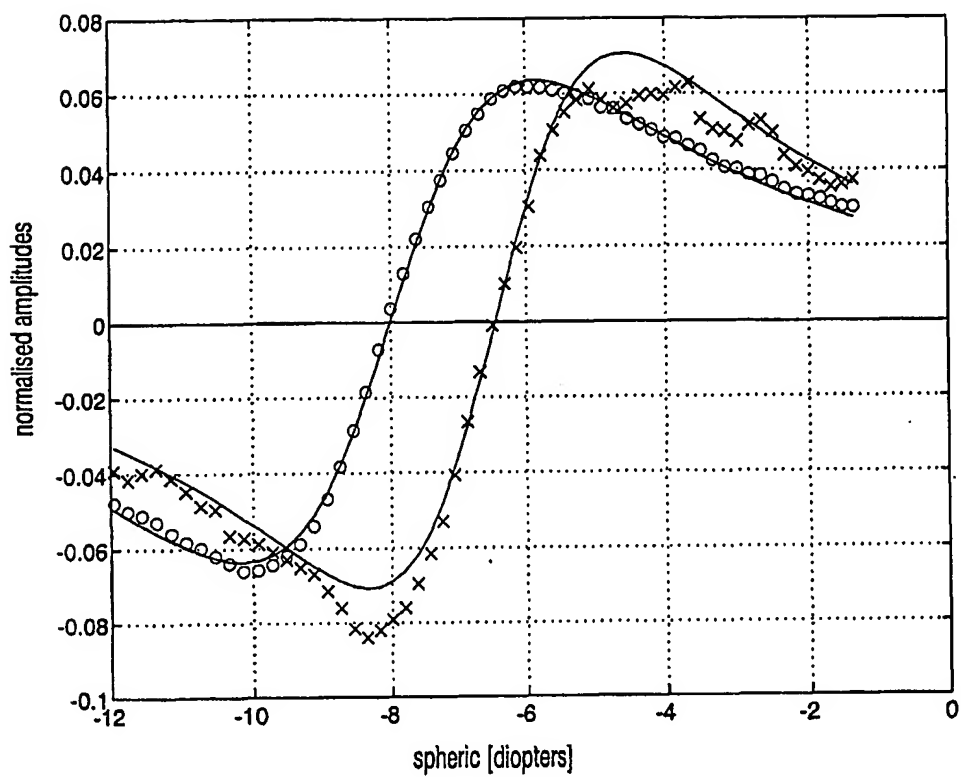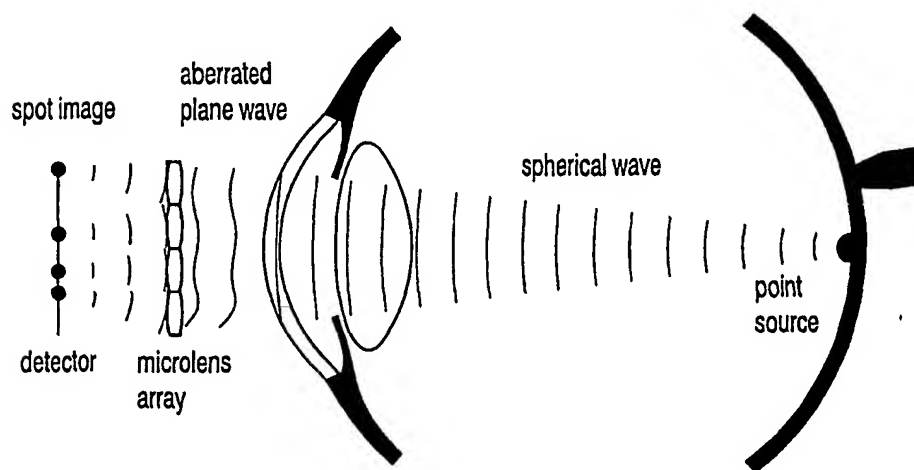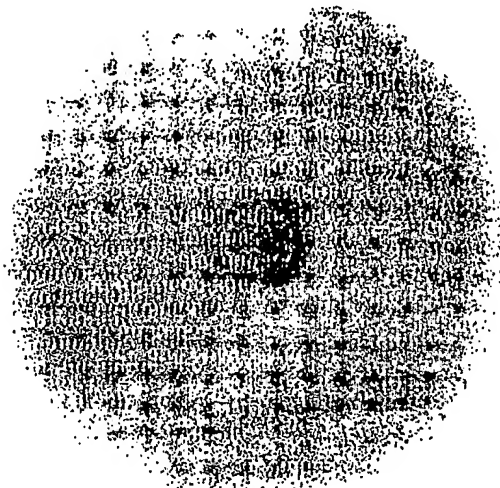
1/4

FIG. 1

FIG. 2
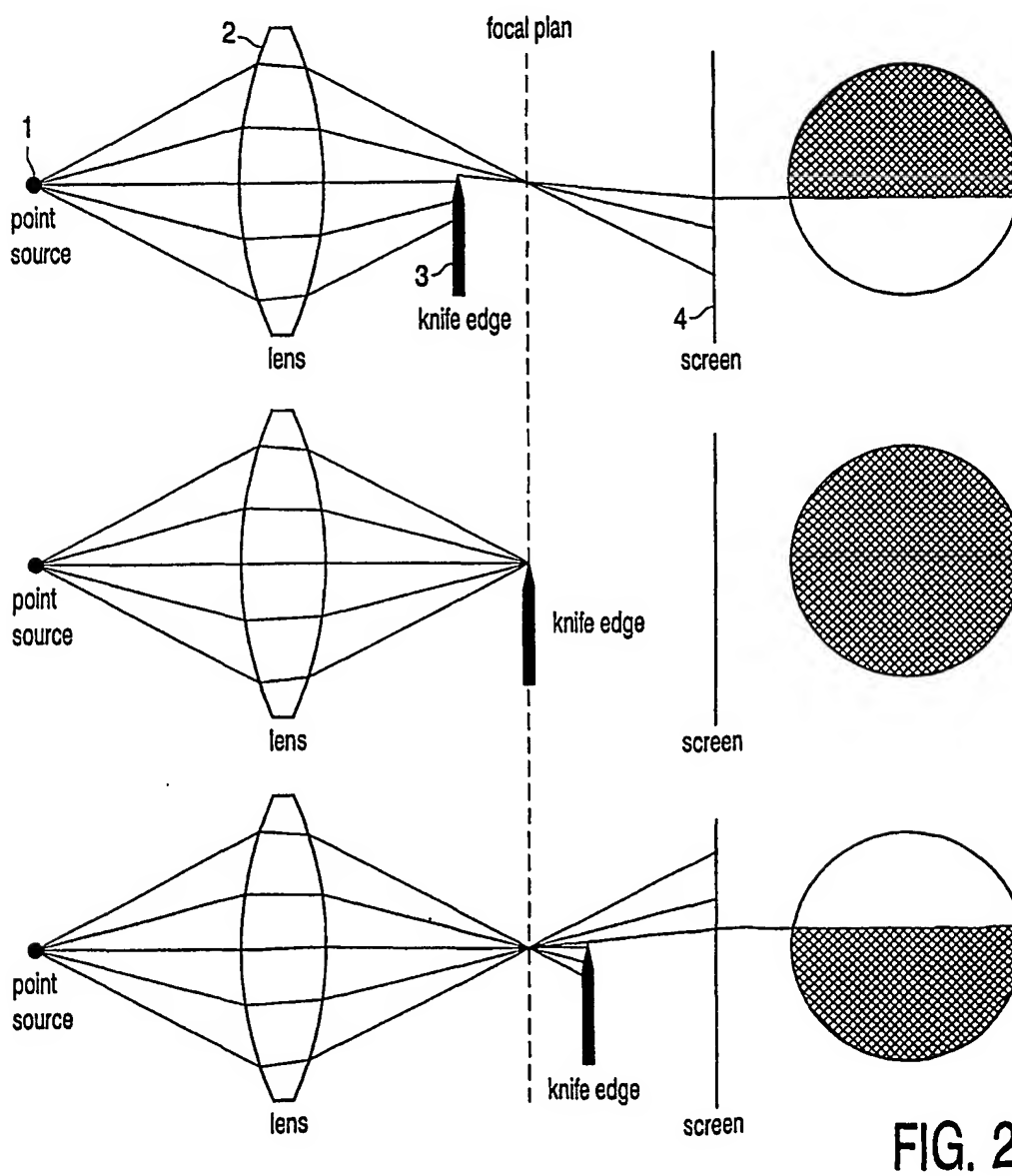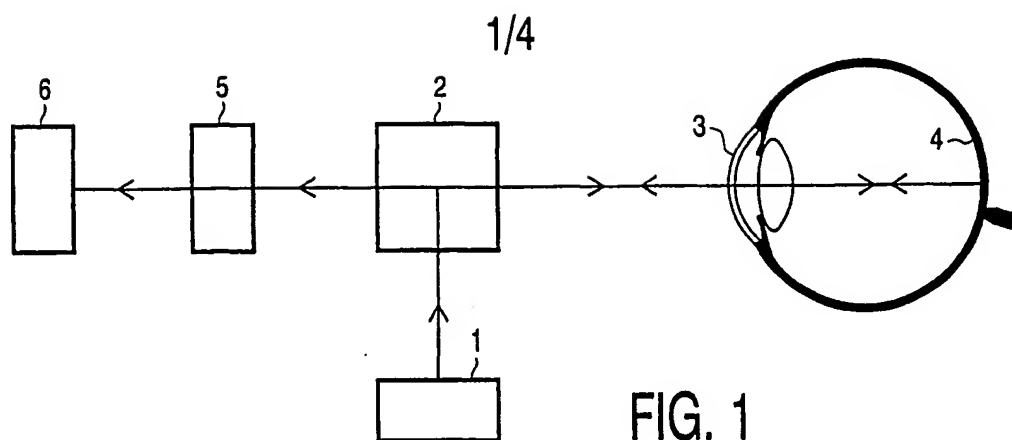
FIG. 3

FIG. 4

FIG. 5

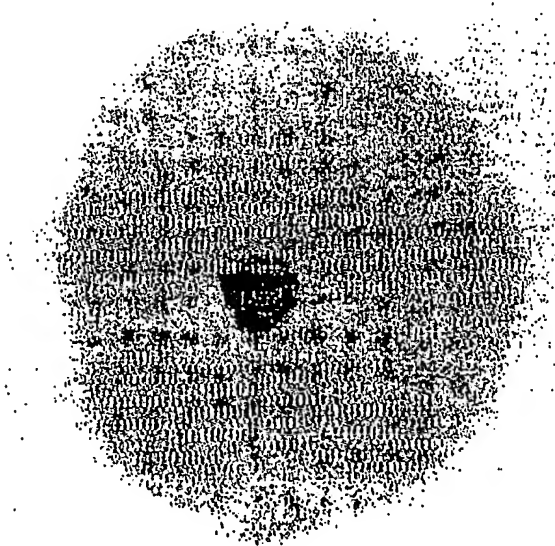Wavefront Analyser recordings

a healthy eye of a 20 years' old person (visus 1.2)

FP (4mm.) = 1.58
FP (9mm.) = 1.1

a cataracteous eye of a 76 years' old person (visus 0.5)

FP (4mm.) = 0.78
FP (9mm.) = 0.44

FIG. 6

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   A61B3/103

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 963 300 A (AMT) 5 October 1999 (1999-10-05) column 6, line 51 –column 10, line 48 ---	1,4,5
A	US 4 707 090 A (HUMPHREY) 17 November 1987 (1987-11-17) column 1, line 42 –column 7, line 48 -----	1,2

[ ] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2001	21/11/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Lemercier, D

Form PCT/ISA/210 (second sheet) (July 1992)

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5963300	A	05-10-1999	WO	0106914 A1	01-02-2001
			AU	5322299 A	13-02-2001
US 4707090	A	17-11-1987	AU	553164 B2	03-07-1986
			AU	7681981 A	06-05-1982
			CA	1171706 A1	31-07-1984
			CA	1192774 A2	03-09-1985
			CA	1172478 A2	14-08-1984
			CA	1171707 A2	31-07-1984
			CH	664888 A5	15-04-1988
			CH	661198 A5	15-07-1987
			DE	3143162 A1	29-07-1982
			GB	2086609 A ,B	12-05-1982
			GB	2112543 A ,B	20-07-1983
			GB	2154756 A ,B	11-09-1985
			JP	1496538 C	16-05-1989
			JP	57131423 A	14-08-1982
			JP	63031214 B	22-06-1988
			US	4640596 A	03-02-1987
			US	4669835 A	02-06-1987
			US	4650301 A	17-03-1987
			US	4560259 A	24-12-1985